Conseil national de recherches Canada
Institut de génie des matériaux
Boucherville (Québec)

National Research Council Canada
Industrial Materials Research Institute
Boucherville, Quebec

STEEL STRIP-CASTING PROGRAMME JUSTIFICATION STUDY

IGM87RT-205-545-G
CNRC 27560

STEEL STRIP-CASTING PROGRAMME

JUSTIFICATION STUDY

By

Henry W. Leon
Hatch Associates Ltd.

For

Industrial Materials Research Institute

Note au lecteur:

Les idées exprimées dans ce document sont celles de l'auteur (ou du contractant) et ne sont pas nécessairement partagées par l'Institut de génie des matériaux ou par le Conseil national de recherches du Canada. L'auteur (ou le contractant) en assume l'entière responsabilité.

Si la demande est suffisante, des exemplaires supplémentaires de cet ouvrage pourront être disponibles dans la seconde langue officielle (français ou anglais).

Note to the reader:

The views expressed in this document are those of the author (or contractor) who assumes their full responsibility. They are not necessarily shared by the Industrial Materials Research Institute of the National Research Council of Canada.

If sufficient requests are received, a copy of this document will be made available in the other official language (French or English).

TABLE OF CONTENTS

SECTION	TITLE	PAGE
1.0	INTRODUCTION AND SUMMARY	1
2.0	USES OF SHEET AND STRIP	4
3.0	CONVENTIONAL MANUFACTURING PROCESS	5
4.0	STATISTICAL DATA	7
5.0	DEMAND	14
6.0	STATUS OF THE STRIP-CASTING PROCESS	21
7.0	JUSTIFICATION FOR STRIP-CASTING	33
8.0	CASTER-MILL CONCEPTS	36
9.0	COST ASSESSMENTS	40
10.0	MINIMILLS	45
11.0	JUSTIFICATION FOR A CANADIAN PROGRAMME	47

1.0 INTRODUCTION AND SUMMARY

In 1986, the National Research Council of Canada commissioned a project to examine the justification for a national programme to develop the continuous casting of steel strip. The scope included:

(a) A comprehensive study to:
- characterize the steel sheet and strip market
- identify the threats to the market
- review the status of strip casting development and examine the justification for the process
- examine the justification for a Canadian R&D programme

(b) A workshop to examine the state-of-knowledge relevant to the technologies in strip casting.

This study covers item (a) and reaches the conclusion that there is significant and immediate justification for a Canadian R&D programme. The key points are:

° The Canadian steel market is now changing from a growth trend to a levelling trend and may subsequently decline. In the U.S. steel market, the growth trend peaked ten years ago and has since been declining rapidly.

° Under these conditions, competitiveness is the key to survival. Many uncompetitive U.S. plants have been shut down in recent years.

° Strip casting has operating and capital cost advantages over conventional existing processes.

° The magnitude of the cost benefits depends on the cast thickness, cast speed and the scale of operation.

° For the assumptions made in this study, potential operating cost savings up to $45 per tonne are assessed, compared to the conventional processing route.

- Capital costs per annual tonne for a new strip caster-mill are assessed at roughly half of the conventional slab caster and hot mill.

- Strip casting processes are under active research and development by at least twenty-three groups in Japan, Europe, and the U.S. Most of these groups are major steelmakers.

- Although none of these processes is yet in operation for tonnage production of carbon steel, Nucor has recently ordered a thin-slab caster combined with a four-stand hot mill, to produce hot band on a commercial basis. This facility is scheduled for operation in 1989.

- Kawasaki Steel has indicated that it may adopt one of the new casting processes when its facilities are scheduled for upgrading in the next decade.

- To remain viable, the Canadian steel industry must adopt strip-casting no later than its foreign competitors.

- It is questionable whether foreign steelmakers who develop and commercially operate a low-cost process themselves will sell it at an acceptable price to a competing steelmaker.

- The steel industry is cognizant of the time and cost that is typically associated with purchasing a new process from an equipment supplier and developing it into a viable production unit.

- There is also the risk that strip-casting processes that are initially put on the market for sale will be obsolete by the time they are installed and operational. It is believed that when the early designs are commercialized (such as at Nucor), the development of more advanced concepts having lower capital and operating costs, will accelerate.

It is thus clear that the commercial introduction of low-cost strip-casting processes is imminent and that Canadian steel producers will have to buy the process either from competing steelmakers or equipment suppliers, with the attendant risks.

It is believed that a Canadian R&D programme would not only provide a focus for the considerable research talent in Canadian Universities, as well as Government and Industry laboratories, but would significantly reduce the risks in adopting the strip-casting process.

2.0 USES OF SHEET AND STRIP

2.1 Definitions

Steel sheet and strip is manufactured from carbon steel, alloy steel or stainless steel and is available up to about 2100 mm wide. It is produced and sold as full-width coil and can also be ordered slit and as cut-to-length flat sheets.

It is produced as "hot-rolled" or "cold-rolled" material. Cold-rolled material can be supplied coated with zinc, lead, aluminium or paint, or plated with tin or chrome.

	Thickness		Width
	Available	Majority	Majority
Hot-Rolled	1.2-12 mm	2-3 mm	1200-1800 mm
Cold-Rolled	0.5-6 mm	0.7-1.2 mm	900-1400 mm
Tin-Mill	Under 0.4 mm		

2.2 Applications

The specific applications of hot and cold-rolled strip are innumerable, but the majority fall into the following principal classifications:

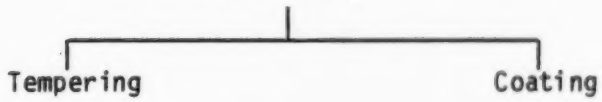
- Motor vehicles
- Containers
- Pipe and tubing
- Stampings and pressings
- Construction
- Appliances

Tin-mill product applications are principally containers (food, beverages, paint, aerosols) as well as bottle caps and kitchen utensils.

3.0 CONVENTIONAL MANUFACTURING PROCESS

The sequential process steps in the conventional manufacture of steel sheet and strip are:

Slab casting
Hot rolling
Pickling
Cold rolling
Annealing



The following is a brief basic description of the first four steps, sufficient for a general understanding of the conventional process stages that may be affected by strip casting.

3.1 Slab Casting

Molten steel flows from the bottom of a ladle into a tundish and then into the casting machine mould(s). The copper mould oscillates and is internally water-cooled, causing a solidified skin to form around the liquid steel. As the strand is slowly withdrawn from the bottom of the mould at 1 to 2 m/min, its surface is sprayed with water to cool the shell until the strand is fully solidified. The continuous strand follows a 90° arc to emerge horizontally and is then cut to slab length by oxygen torches.

For carbon steel sheet and strip applications, cast slabs are typically 180 mm to 250 mm thick and 600 mm to 2100 mm wide. Maximum slab length is about 12 m.

3.2 Hot Rolling

The cast slabs are reheated to about 1200°C in a furnace. As each slab emerges, it is descaled and initially rolled in the roughing stand(s) to

form a long "transfer bar" about 20 mm to 40 mm thick. The bar is quickly transferred by roller table to the finishing mill, where each rolling stand sequentially reduces the thickness by about 30%. There are typically 5 to 7 finishing stands, allowing reduction down to a minimum thickness of 1.2 mm. Maximum thickness is about 12 mm but the majority of production is 2 to 4 mm thick. The steel emerging from the finishing stands at about 900°C and moving at 10 to 20 m/s, is spray-cooled to about 600°C before entering the coiler. The coiled product is "hot band" and typically has a specific weight of 10 to 20 kg/mm width.

The largest hot strip mills are up to 700 m long, from reheat furnaces to coiler.

3.3 Pickling

To remove oxide scale and clean the surface of the steel, the hot-rolled coil is unwound and fed through a continuous pickler, at a speed of 5 to 10 m/s. The strip sequentially passes through a series of acid and water rinse tanks or sprays, followed by air dryers. At exit, the strip is lightly oiled to provide corrosion protection and is again coiled.

3.4 Cold Rolling

In addition to reducing the thickness of the material by up to about 90%, the cold rolling process improves the surface finish and the strength of the steel. A modern cold rolling facility is typically a tandem mill containing up to six rolling stands. The pickled coil is unwound and fed sequentially through the rolling stands. Exiting at up to 40 m/s, the finished strip is again coiled.

The finished thickness of cold-rolled sheet is typically 0.5 to 2 mm, but the majority of demand for automotive and appliance markets lies between 0.7 and 1.2 mm.

4.0 STATISTICAL DATA

4.1 World Perspective

As a guide to Canada's steel production relative to other countries, the following table shows our "raw steel" production in comparison with the USA and other non-communist countries, for 1984 (Source AISI).

	Million Tonnes	%
Canada	14.6	3.3
USA	84.1	19.0
Japan	105.8	23.9
Western Europe	152.9	34.6
Others	84.7	19.2
	442.1	100.0

Fig. 1 graphically compares the historical trends of Canadian and U.S. shipments since 1950.

4.2 Canada and USA

The significance of sheet and strip product, including coated and tin mill products, is apparent in the following table of shipments for 1985 (Source: Statistics Canada, AISI). The eleven-year trend of Canadian shipments shown in Fig. 2 indicates that the proportion of sheet and strip has remained roughly constant, at about half of all steel mill shipments.

	CANADA		USA	
	Million Tonnes	%	Million Tonnes	%
Sheet and strip products	5.88	50	37.13	56
All other steel mill products	5.80	50	29.27	44
	11.68	100	66.40	100
Carbon steel			58.51	88
Alloy steel			6.75	10
Stainless steel			1.14	2
			66.40	100

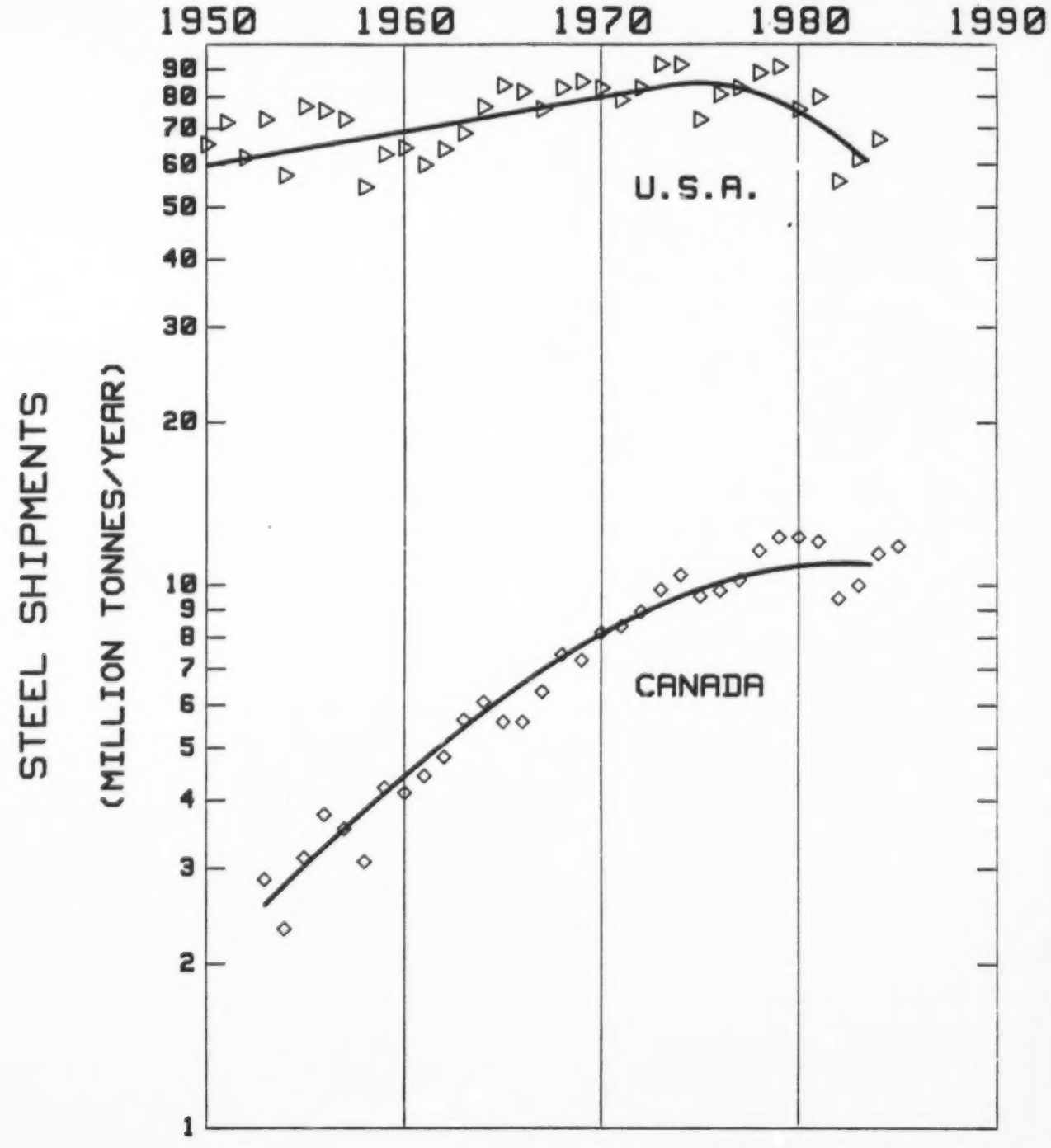


FIGURE 1

Source: AISI

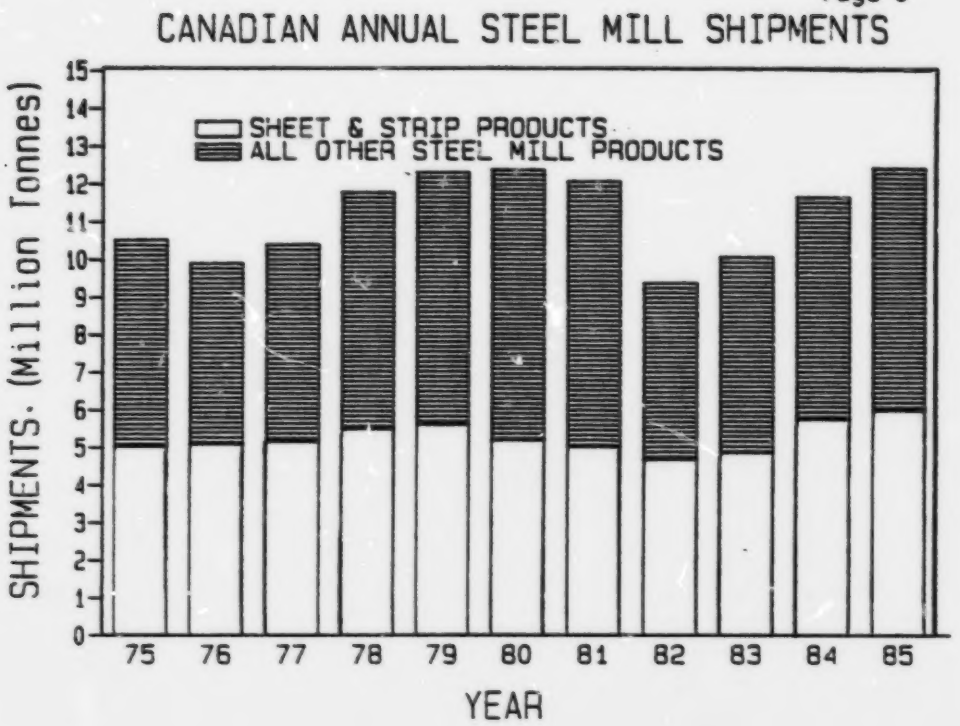


FIGURE 2

Source: Statscan

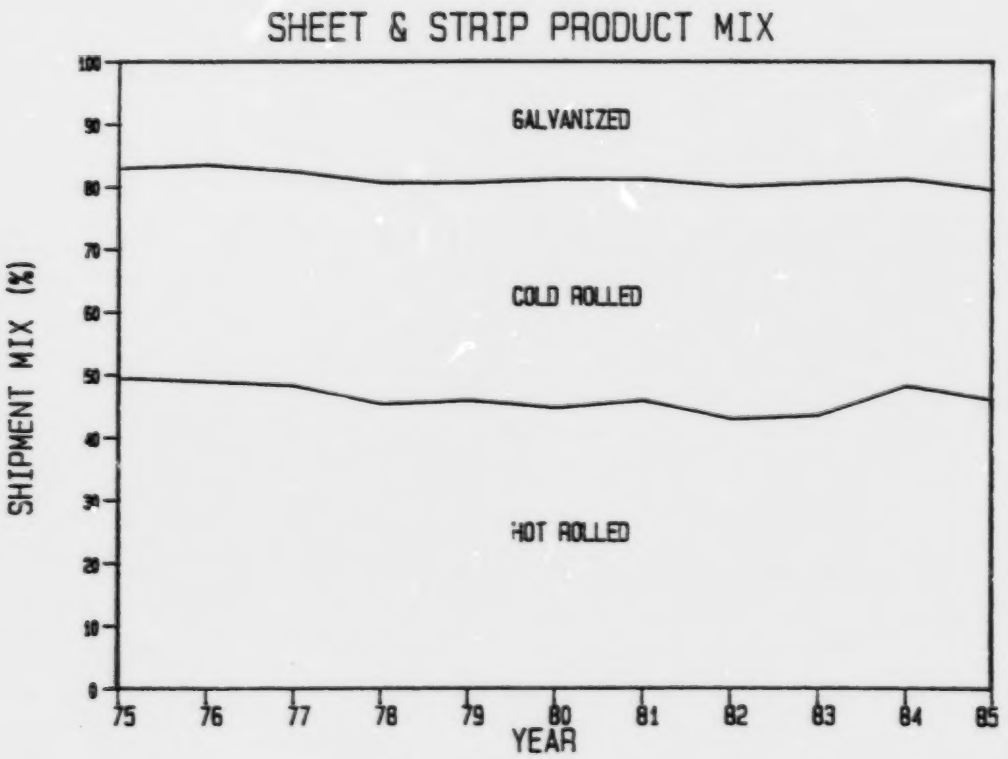


FIGURE 3

Source: Statscan

4.3 Product Mix of Sheet and Strip

Fig. 3 illustrates the mix of hot and cold-rolled sheet and strip shipments for the last eleven years. It demonstrates a small decline in the percentage of hot-rolled shipments being balanced by the increasing percentage of galvanized shipments.

For 1985, the percentage mix was:		
	Hot rolled	46.1%
	Cold rolled	25.0%
	Galvanized	20.4%
	Tin plate	8.5%
		100.0%

4.4 Distribution and Use of Sheet and Strip

The following tabulation illustrates the uses of sheet and strip in Canada, as a percentage of domestic consumption excluding exports (Source: Statistics Canada).

	1975		1985		10 Year Change
	Thousand Tonnes	Mix	Thousand Tonnes	Mix	
Motor vehicles and parts	946	20.4%	1,513	29.9%	60%
Steel service centres	566	12.2%	1,051	20.8%	86%
Pipes and tubes	888	19.2%	763	15.1%	-14%
Stampings, pressings, coating	574	12.4%	391	7.7%	-32%
Contractors & construction	534	11.5%	501	9.9%	- 6%
Machinery	210	4.5%	147	2.9%	-30%
Appliances and utensils	175	3.8%	106	2.1%	-39%
All others	225	4.9%	62	1.2%	-72%
	4,626	100.0%	5,052	100.0%	9.2%

This comparison demonstrates the ten-year trend of increased consumption by the automotive industry and the increased distribution through service centres. These increases more than balance the declines in other sectors. Service centres principally supply a warehousing and distribution function, as well as limited processing including cutting, slitting and banding. Their shipments to users are distributed in proportions roughly similar to those of the primary producers.

4.5 Exports and Imports

Fig. 4 illustrates the percentage of sheet and strip exports and imports for the last eleven years. During this period, exports averaged about 13% of sheet and strip shipments, and imports averaged about 8½%. Excluding the major variations in 1981 and 1982, sheet and strip exports in this period have been increasing at an average rate of about 4% per year, but imports have been increasing at nearly 10% per year.

In 1985, total exports and imports of sheet and strip were roughly similar, as follows:

	EXPORTS		IMPORTS	
	Tonnes	%	Tonnes	%
Hot rolled	370,000	13.5	388,000	14.1
Cold rolled	148,000	9.9	256,000	17.2
Galvanized	215,000	17.7	201,000	16.6
Tin plate	94,000	18.7	1,000	0.1
Total	828,000	13.9	846,000	14.2

The percentages represent the proportion of shipments of that specific product.

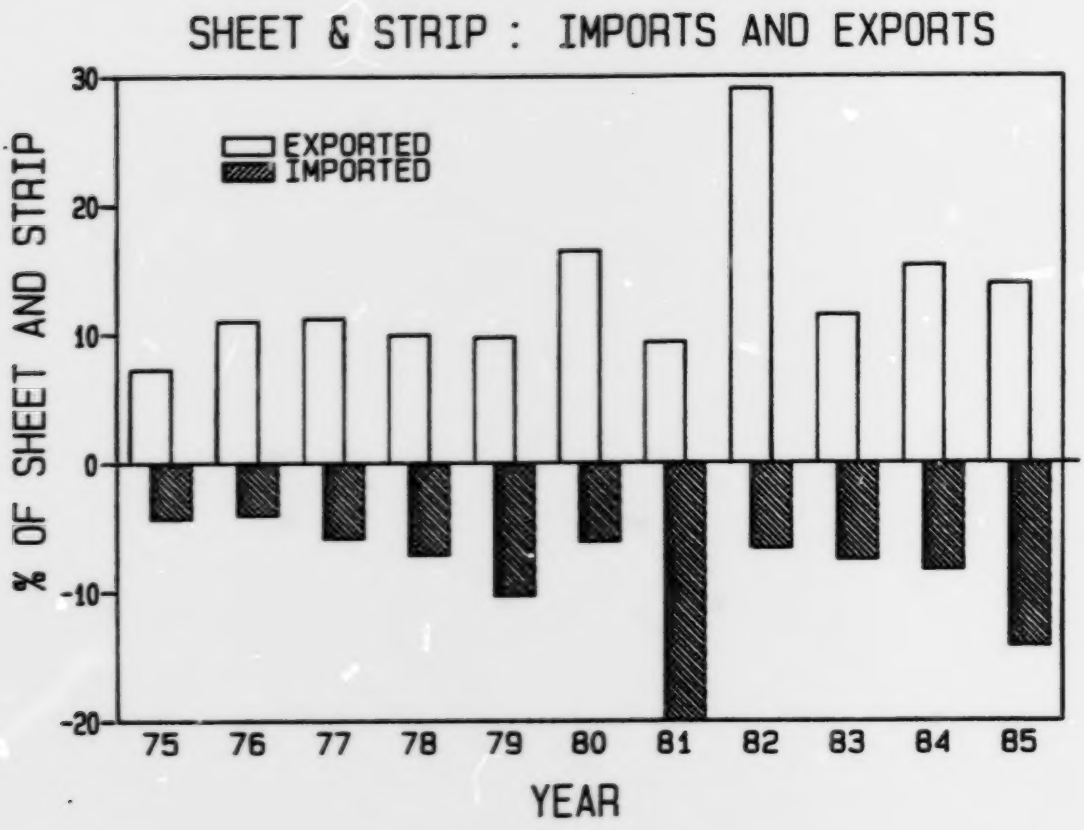


FIGURE 4

Source: Statscan, AISI

4.6 Statistical Trends

The following average annual increases apply to the period from 1975 to 1985:

	Average Annual Increase	For 1985
Shipments of all rolled steel	1.67%	11.7 million tonnes
Shipments of all sheet and strip	1.79%	5.9 million tonnes
Population	1.11%	25.4 million
Gross Domestic Product (Constant Dollars)	2.65%	$490 billion

Although ten years is a relatively brief period for determining secular trends, the percentages clearly illustrate that steel shipments, including exports, are of declining significance relative to GDP. In 1985, the dollar value of all rolled steel shipments represented 1.6% of GDP.

It also indicates that steel shipments on a per capita basis, have been increasing marginally. For 1985, the shipments represent about 460 kg per capita.

These trends are further discussed in Section 5.

4.7 Prices

The following are typical sheet and strip prices quoted f.o.b. by Stelco and Dofasco in October, 1986.

	Thickness (mm)	Width (mm)	$/Tonne
Hot-rolled sheet	3.0 - 4.5	1500	528
Hot-rolled strip	3.0 - 4.5	300	554
Cold-rolled sheet	1.0 - 1.6	1500	638
Cold-rolled strip	1.0 - 1.6	300	682
Galvanized sheet	2.2 - 2.5	1500	671

Based on these prices, total mill revenue from Canadian sheet and strip shipments in 1985 was about $ 3½ billion.

5.0 DEMAND

Having reviewed production statistics, it is essential to examine future demand. The picture that emerges is not an optimistic one for the steel industry.

5.1 Economic Scenario

A review of the history of consumption of a number of basic materials shows that since the Industrial Revolution, economic expansion has been marked by the increasing consumption of materials. However, U.S. consumption of traditional basic materials such as steel, appears to be levelling off in per capita terms (Fig. 5), but has clearly been declining for most of this century in terms of gross national product (Fig. 6). The latter is a measure of the relative importance of the material in the economy.

Canadian steel consumption data for the last decade suggest that similar trends are occurring, but are later than in the U.S.

A similar long-term trend has occurred with another traditional basic material, cement. For more recent basic materials introduced in the last fifty years, such as aluminum, there is initial evidence that similar demand patterns are emerging.

Thus, although economic expansion continues, the consumption of a number of basic materials is levelling off, and in terms of GNP, some are declining. This apparent contradiction can be explained by the following factors:

- Substitution of alternative materials
- Increasing efficiency of material utilization
- Saturated markets

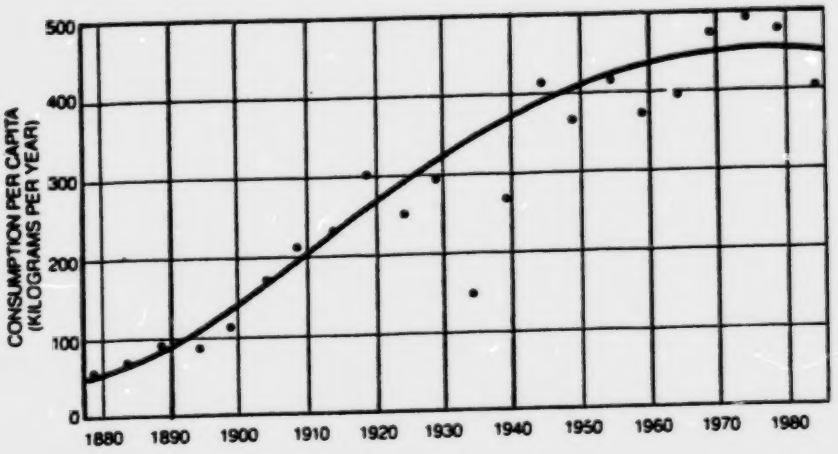


FIGURE 5

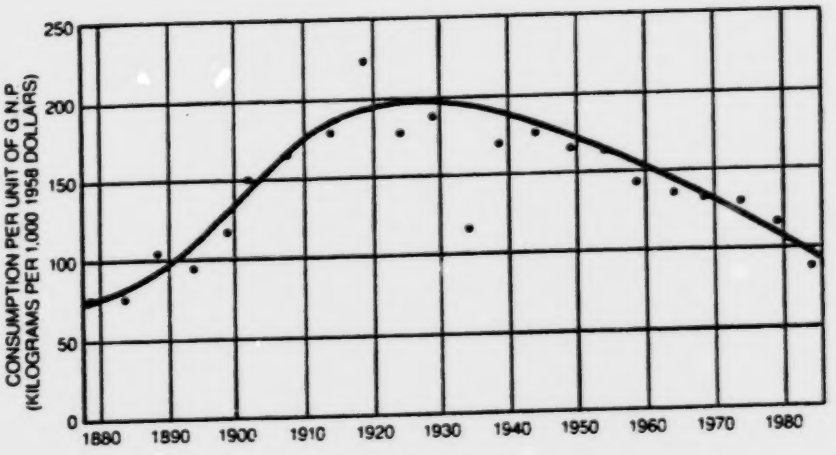


FIGURE 6

Source: Scientific American

5.2 Steel Scenario

All of these factors have influenced the demand for steel. For example, the automotive market accounts for 15% to 20% of North American steel demand. With the objective of reducing fuel consumption in recent years, and in the face of competition from imports, smaller and lighter cars have been built. Since 1975:

- The average weight of a car built in North America has dropped from 1,700 kg to 1,500 kg.
- The mild steel content declined from 60% to 50%.
- The aluminum and plastic content rose from 6% to 15%.
- The content of specialty steels having higher strength and corrosion resistance rose from 3% to 8%.

These trends are illustrated in Fig. 7.

Another example is provided by the containers and packaging market, where steel is being progressively replaced by plastic and aluminum for cans and containers. In the last ten years, these substitutions have resulted in a 30% decline in U.S. shipments of tin mill products.

These are clear examples of "materials substitution" and "efficiency of material utilization".

With respect to the "saturation" factor, it is recognized that much of the North American demand for steel in the past came from building infrastructure, such as highways, railroads, public transportation, commercial building and housing. With the possible exception of commercial building, demand from these markets has been declining. Furthermore, over the period of increasing affluence, most adults have acquired cars and most households have purchased stoves, refrigerators, washers and dryers. Thus, a rising

growth market has become saturated and changed into a levelling market for replacement of worn cars and appliances. Automotive sales data (Fig. 8) provide an excellent example of this pattern. In the Canada-U.S. market, sales of new domestic and commercial vehicles grew at an average annual rate of about 3½% until the mid-seventies. Since then, average sales growth has been virtually zero.

In summary, these are the principal factors that have influenced the levelling-off in demand for steel, and the trends are probably irreversible. A recent study by Chase Econometrics predicts that U.S. consumption of steel will decline by about 7% in the next ten years. For sheet and strip, including coated and tin mill products, a 5% decline is forecast (Fig. 9).

5.3 Production Capacity

Accepting the level or declining demand scenario, it is clear that existing steel plant capacity is more than adequate to supply the basic trend, as well as the cyclical peaks. It is also an economic imperative that countries having lower production costs and capacity surplus to their own needs, will export to countries having higher production costs. Relative production costs are also affected by currency exchange rates and will influence the balance of exports and imports.

All of which suggests that if Canada's steel production costs are relatively higher than those of other countries, sufficient steel will ultimately be imported to cause a contraction in our industry's capacity. Conversely, if our production costs are lower, exports would increase and allow the steel industry to utilize its full capacity and sustain its profitability.

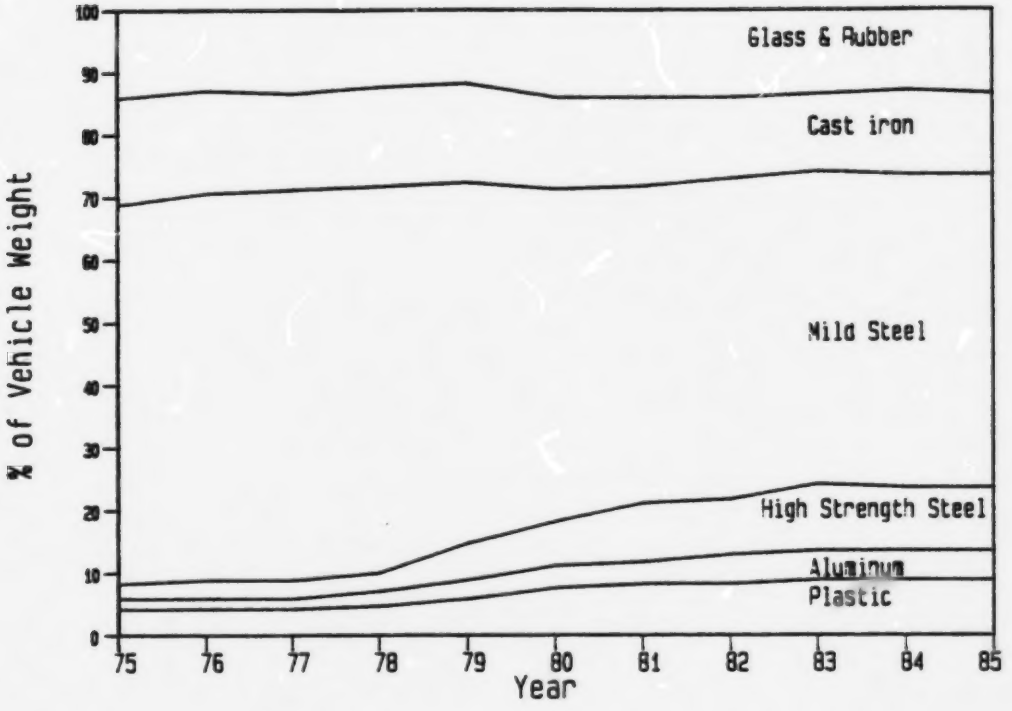


FIGURE 7

Source: Scientific American

NEW VEHICLE SALES

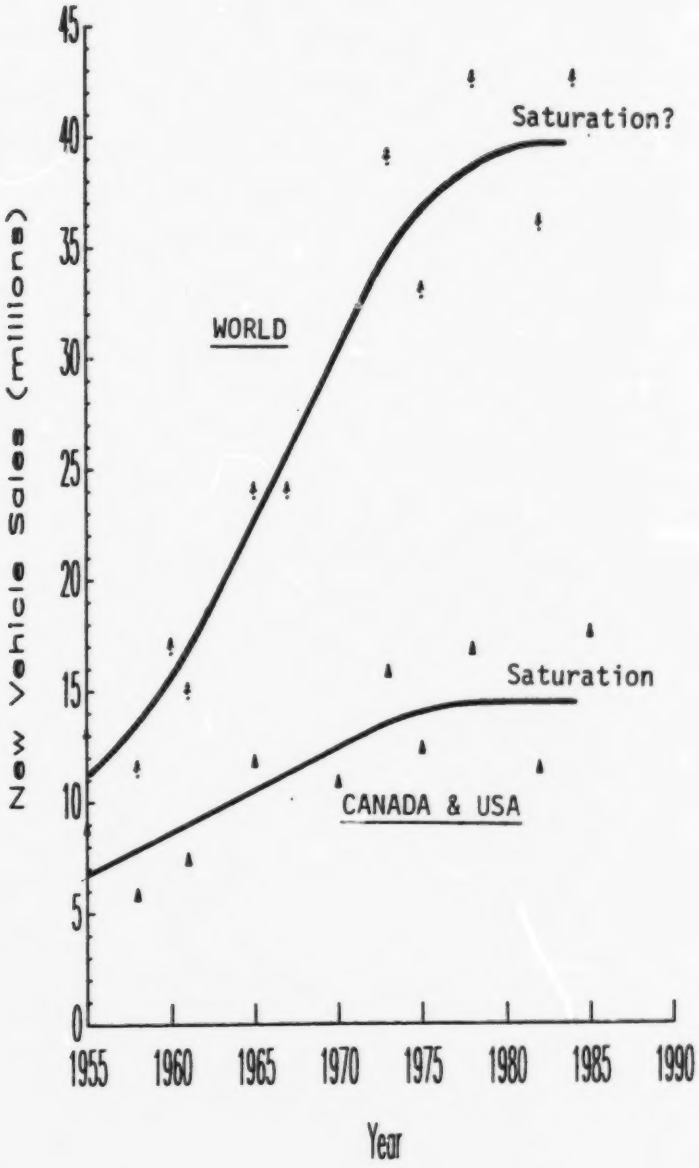


FIGURE 8

Source: Scientific American, A.P.M.A.C.

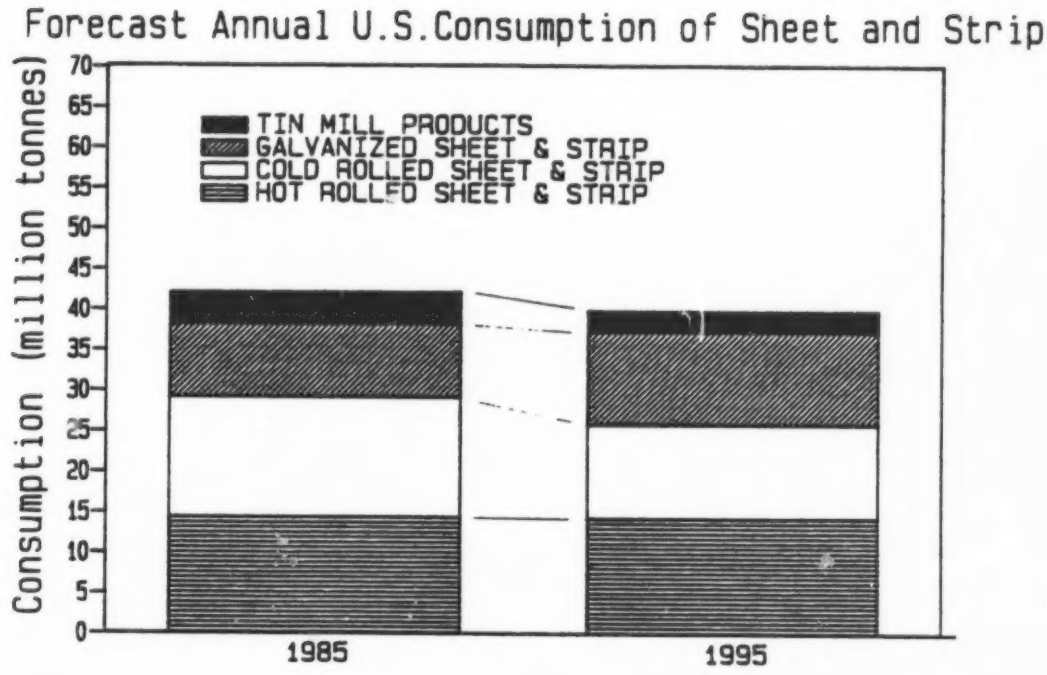


FIGURE 9

Source: Iron & Steel Engineer

6.0 STATUS OF THE STRIP-CASTING PROCESS

An NRCC study, "The Direct Casting of Steel Strip" provides comprehensive and detailed coverage of the process and its history, which commenced with Henry Bessemer in the nineteenth century.

This section is a brief review of the known process alternatives for casting steel strip and a listing of those that are currently under active development. Much of the data are drawn from the Fifth International Iron and Steel Congress held in early 1986, as well as from recent literature.

With one exception, none of the processes is currently in commercial use. They are all in a laboratory or pilot plant stage and are sized to cast narrow material, typically less than 600 mm wide. Based on the nature of published data, it appears that much of the development work is being carried out in Japan, while U.S. and European programmes appear relatively limited.

Although most of the processes are conceptually simple, it seems clear from the available data that there are many practical aspects that must be fully developed to achieve successful commercial implementation. Among these items are:

(a) Acceptable product quality, equal to or better than available from conventional production processes
(b) Consistent dimensional characteristics of the product
(c) Reliable feeding and distribution of the liquid steel

There are three basic casting machine concepts, each of which includes a number of variations:

- Belt casters
- Twin-roll casters
- Single-roll casters

The twenty-three companies and groups known to be actively developing these concepts are listed in Fig. 10.

GROUPS	BELT	TWIN-ROLL	SINGLE-ROLL	OTHER
U.S.A.				
Allegheny-Ludlum			X	
Allied-Signal			X	
Armco-Westinghouse (Consortium)			X	
Bethlehem (Consortium of four)		X		
Bethlehem - U.S. Steel (Consortium)	X			
National-Battelle			X	
Nucor	X			X
JAPAN				
Hitachi Zosen	X	X		
Kawasaki Steel	X	X		
Kobe Steel		X		
Nippon Kokan		X		
Nippon Metal		X		
Nippon Steel		X		
Sumitomo Metal	X			
EUROPE				
British Steel	X			
CSM		X		
Danieli	X			
IRSID		X		
Krupp	X			
Mannesmann Demag	X			
Osprey	X		X	
SMS-Concast				X
Voest-Alpine		X	X	

LIST OF ACTIVE DEVELOPMENT GROUPS

FIGURE 10

6.1 Belt Casters (Fig. 11)

Twin-belt casters consist of two continuous moving thin steel belts, as in a belt conveyor, forming a parallel cavity into which the molten steel is introduced. The back of each belt is cooled by water jets, thus forming a mould in which the walls move continuously with the solidifying strand. The caster can be installed horizontally, inclined, or vertically. The recent machines installed for development purposes are designed to produce thin slabs ranging from 10 to 80 mm in thickness, the average being about 30 mm.

A similar system which has been used for non-ferrous applications, but has potential for casting steel, utilizes metal blocks connected together like a caterpillar tread, instead of thin steel belts.

There is also a single-belt system where the strand thickness is built up by spray deposition of liquid steel particles onto a moving substrate which consists of ceramic blocks attached to a horizontal belt. The deposit is then detached from the substrate and immediately rolled to form a product about 5 mm thick.

Another system utilizes a series of iron moulds connected together to form a train which moves on tracks past a stationary ladle and tundish. In effect, the moulds form a long shallow trough into which the liquid steel is poured. This system has been used to cast slabs about 60 mm thick by 500 mm wide.

6.2 Twin-Roll Casters (Fig. 12)

Twin-roll casters typically consist of a pair of internally-cooled rolls rotating on parallel axes, with the cylindrical faces separated by a gap equal to the thickness of the cast strip. One of the rolls has flanged ends, thus forming the ends of a pool into which liquid steel is introduced. A steel skin solidifies on the rotating rolls, to form the faces of the strip. The roll gap can be sized so that the two skins are bonded together in the nip, or it can be made wider so that a liquid core is formed and

subsequently solidified as the strip is withdrawn. Casters of this type are typically arranged to withdraw the strip downwards, either vertically or inclined.

A variation of this concept shown in Fig. 12 has one large roll, with a smaller roll at the 1 o'clock position. The liquid steel is fed from a tundish through an alumina-graphite nozzle onto the roll surface.

A unique twin-roll concept developed in the 1960's is the "inside-the-ring" caster, where a shallow liquid pool is introduced inside a large rotating drum that is externally cooled by water sprays. A smaller drum rotates in the liquid pool to form the upper face of the strip. Operation of this pilot-scale unit was discontinued in 1971.

These development units are designed to cast a range of thicknesses from about 1.0 mm to 60 mm. Grades cast include iron, carbon steels, stainless and high-silicon steels.

6.3 Single-Roll Casters (Fig. 13)

The various single-roll casters differ principally in the method of applying the liquid steel to the surface of the rapidly rotating roll. The "melt-drag" method relies on surface tension to drag the liquid steel from the holding vessel, whereas the "planar-flow" method utilizes ferrostatic head to eject the liquid onto the roll. Other methods include spray deposition of liquid steel particles onto the top of the roll and shallow immersion of the roll in a liquid pool.

The development units are designed to cast a range of materials from .025 to 2 mm thick. With the thinnest materials, apparent cooling rates as high as 10^4°C/second are achieved, causing rapid solidification and producing an amorphous (non-crystalline) product. This material can have unique strength, corrosion and magnetic properties, applicable to special products.

Allied-Signal Corp. is the only U.S. company so far known to have adopted this process for commercial use, producing an amorphous ribbon less than 0.1 mm thick called Metglas.

6.4 Other Casters

An evolutionary development of conventional slab casting is the thin-slab caster from SMS Concast. The principal conceptual difference is in the unique design of the mould which is funnel-shaped (Fig. 14). It is wide enough at the top to accept a ceramic pouring shroud, but narrowed at the bottom to form a strand about 50 mm thick, across the full width of up to 1600 mm. As a 50 mm thick strand would be fully solidified in about one minute, the strand support system below the mould is relatively short.

With a casting speed of 6 m/min., production rate would be comparable to a large conventional slab caster although the thin-slab caster would be no larger than a typical first-generation low-head billet caster installed in the nineteen-sixties.

A full-size development unit has operated since 1985 in a West German foundry. SMS Concast recently sold a thin-slab caster and four-stand hot mill to Nucor. This equipment will be installed in a greenfield U.S. mini-mill and is scheduled for commercial operation in 1989. Design capacity is 800,000 tons/year of hot band.

6.5 Casting Rates

To graphically compare the casting rates and thicknesses of the principal processes with conventional slab casting, they have been assembled as domains in Fig. 15. Each domain is an envelope containing the known data for that process, and the casting rates are all based on a 1 m width of product.

It will be apparent that the casting rates of twin-roll and single-roll casters are significantly less than for conventional slab casters. However, it must be emphasized that most of the roll caster data are based on laboratory-scale machines. It is believed that higher casting rates will be achieved on larger machines ultimately developed for production use.

Electromagnetic containment may facilitate higher production rates, and it is believed that the Armco-Westinghouse group is developing this approach.

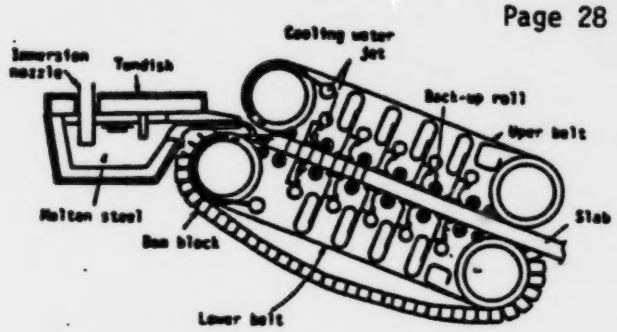
6.6 Product Quality

Allegheny Ludlum has done extensive development work on the single-roll caster, principally for casting Type 304 stainless steel. In 1984, the first commercially-finished coils produced by this process were displayed at the ASM Metals Congress in Detroit. The following quotation summarizes their conclusions:

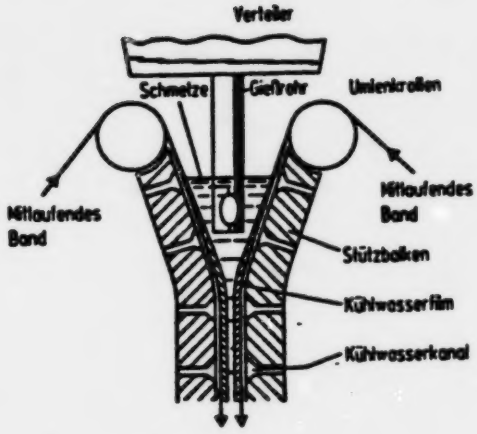
"The yield and ultimate tensile properties of the as-cast strip were lower than those of conventionally produced material. The yield and ultimate strengths of the strip after cold rolling and annealing were essentially the same as conventionally-produced strip. The grain sizes were also similar to conventional material."

"The strip casting process has many problems and potentials. The surfaces have to be nearly perfect, being free from cracks, tears, folds and excessive scale. The thickness of the strip has to be uniform across the width and throughout the length. Any internal shrinkage voids or cracks have to be minimized, since hot rolling is not provided to correct these flaws. Sufficient work has been done to prove that these requirements can be achieved, and that strip can be produced with properties that are equivalent to those of conventionally-produced strip."

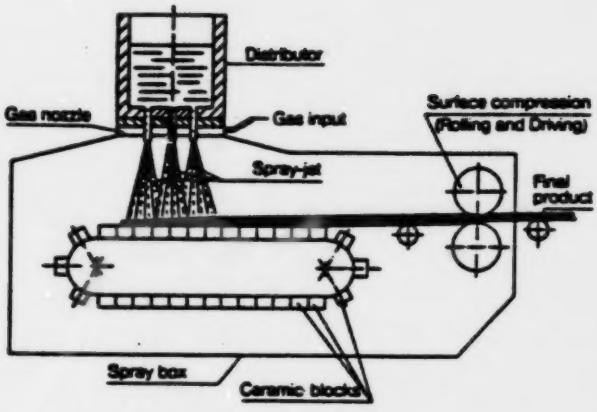
"The strip casting process offers the potential of producing flat-rolled products at lower capital and processing costs. It also may permit the production of some alloys which have not been economical to produce by conventional methods, opening the possibilities for new and improved alloys".



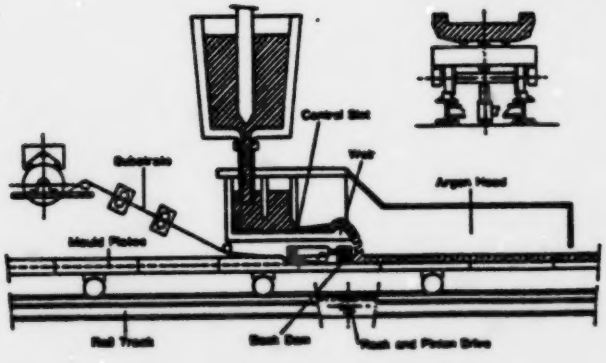
TWIN-BELT INCLINED
(HAZELETT)



TWIN-BELT VERTICAL
(HITACHI)

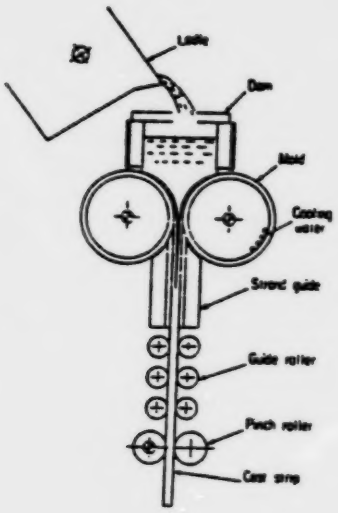


SINGLE-BELT, SPRAY DEPOSITION
(OSPREY & MANNESMANN)

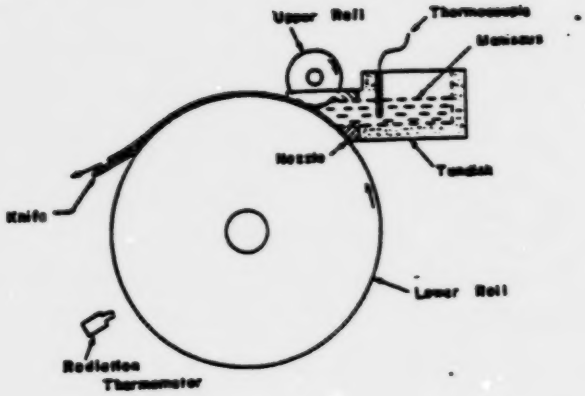


MOVING TROUGH
(BRITISH STEEL)

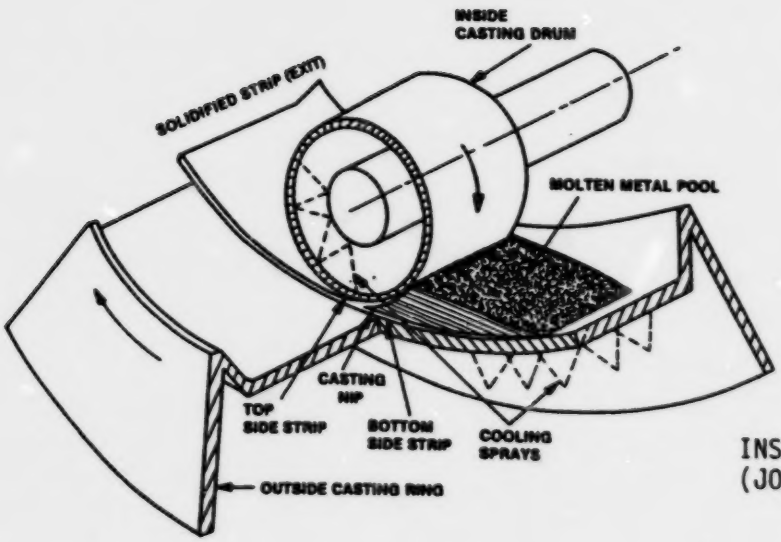
BELT SYSTEMS
FIGURE 11



HITACHI ZOSEN



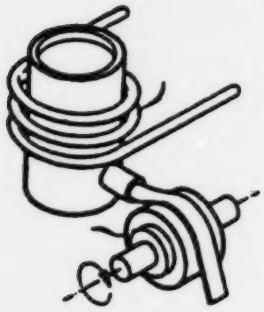
NIPPON METAL



INSIDE-THE-RING
(JONES & LAUGHLIN)

TWIN-ROLL SYSTEMS

FIGURE 12

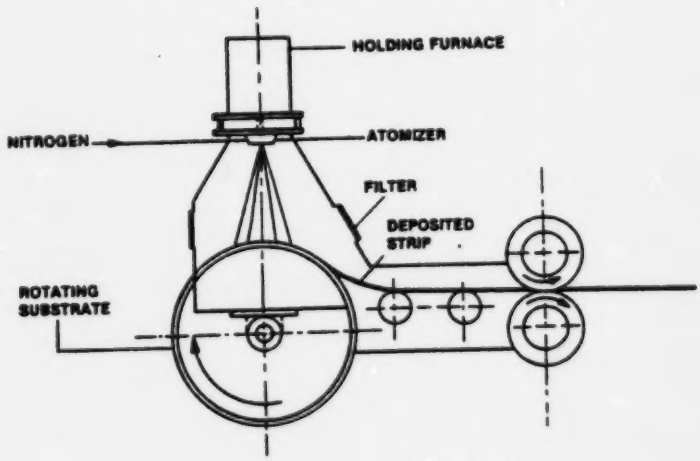


MELT DRAG

PLANAR FLOW

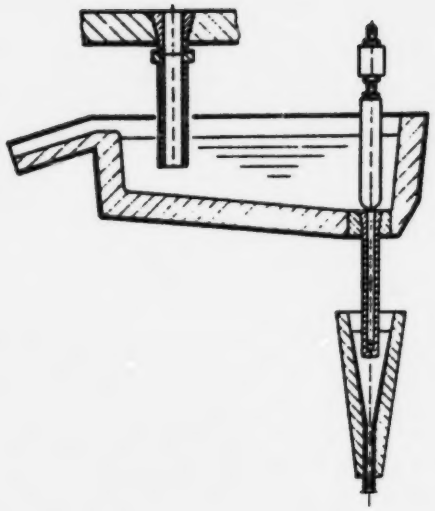
MELT SPINNING

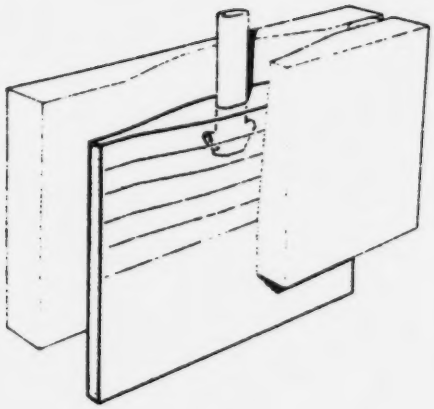
SPRAY DEPOSITION

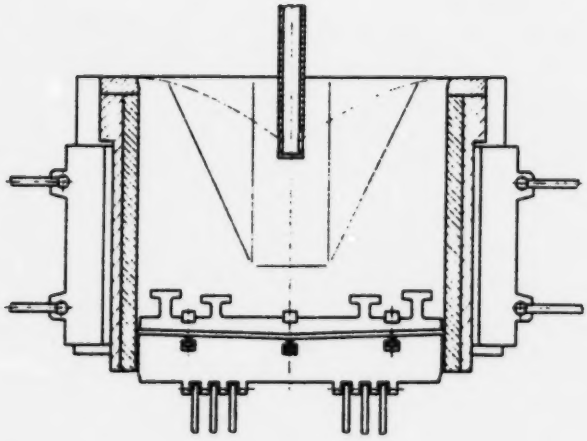


SINGLE-ROLL SYSTEMS

FIGURE 13







THIN-SLAB CASTER MOULD

FIGURE 14

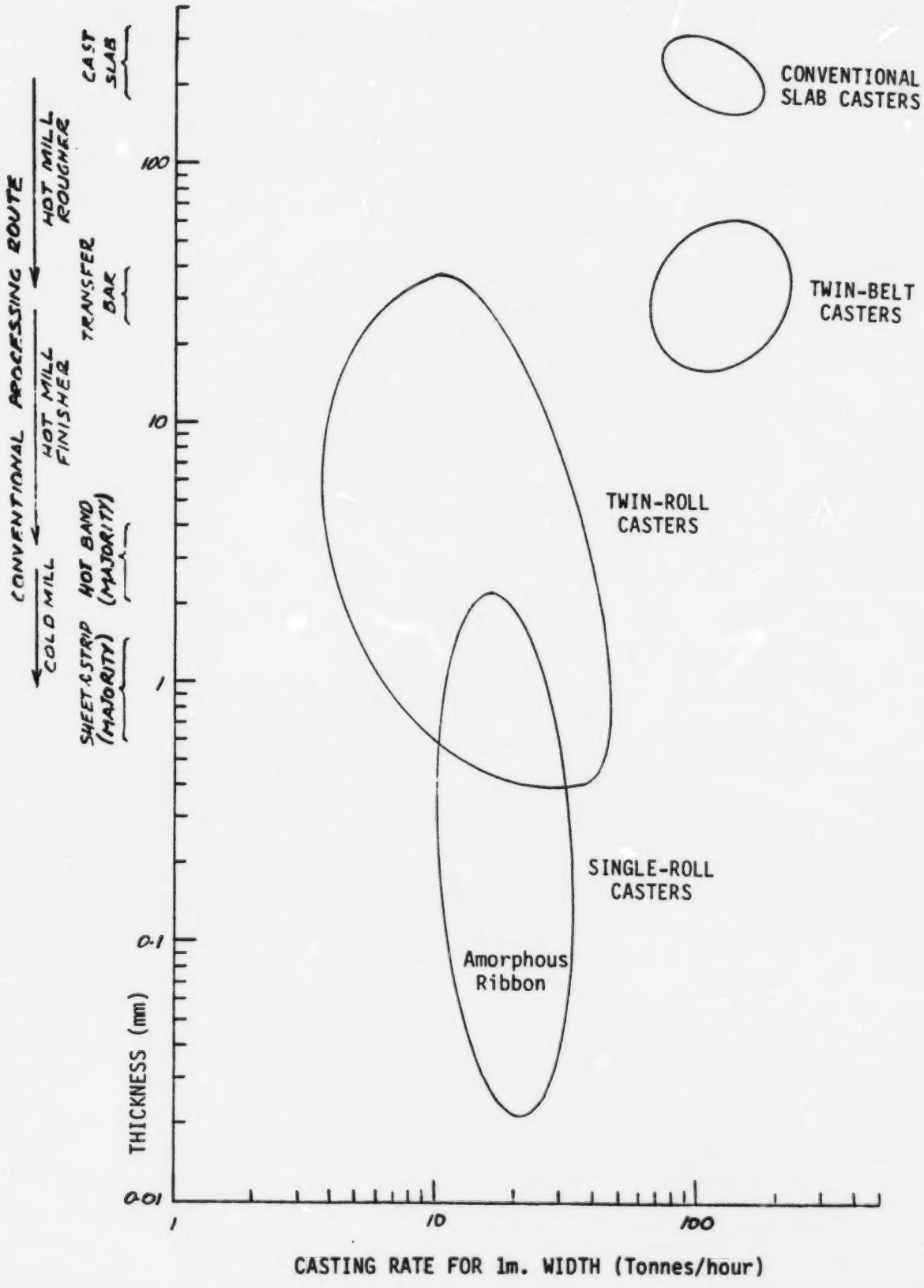

CONVENTIONAL PROCESSING ROUTE
HOT MILL ROUGHER
HOT MILL FINISHER
COLD MILL
CAST SLAB
TRANSFER BAR
HOT BAND (MAJORITY)
SHEET & STRIP (MAJORITY)
CONVENTIONAL SLAB CASTERS
TWIN-BELT CASTERS
TWIN-ROLL CASTERS
SINGLE-ROLL CASTERS
Amorphous Ribbon
THICKNESS (mm)
100
10
1
0.1
0.01
1
10
100
CASTING RATE FOR 1m. WIDTH (Tonnes/hour)

FIGURE 15

7.0 JUSTIFICATION FOR STRIP-CASTING

7.1 Incentives

The incentives for casting a relatively thin section can be rationalized as follows.

Caster

The nature of liquid steel solidification on a cooled surface is such that during phase change from liquid to solid, the rate of heat removal decreases as the thickness of the solidified layer increases. In other words, the thinner the cast product, the higher the solidification rate. For example, a 250 mm thick section produced in a conventional slab caster solidifies in about 22 minutes, but a 25 mm thick section would solidify in 0.22 minutes. Thus in decreasing the thickness of the cast section to one-tenth, the solidification time decreases to one-hundredth. Therefore, if both of these thicknesses were to be cast in the same machine, the thinner section could be produced at ten times the throughput rate of the thicker section. Alternatively, the thinner section could be produced at the same rate as the thicker section in a machine of one-tenth the size. The significance is that a thin section can be cast on a machine that is less expensive than a slab caster of comparable capacity.

Direct Rolling

As the casting speed of a thin section is faster than in conventional slab casting, it facilitates direct rolling by connecting the caster unit directly to a hot mill. This would minimize or eliminate the need to reheat the cast section and thus be less costly than the conventional route.

Hot Mill

The number of mill stands or passes required to reduce a slab to hot band thickness in a conventional mill is a function of the total reduction. For example, a 250 mm thick slab rolled to 3 mm thickness would require 11 or more passes, whereas a 25 mm thick slab requires about 6 passes.

Once again, the significance is that a thin section can be rolled to finished thickness in a mill that is less expensive than a conventional mill of comparable capacity.

To summarize, it is clear that the justification for the strip casting process is due to utilizing smaller equipment and fewer steps to manufacture the product. To attempt to quantify these potential benefits, it is necessary to postulate a caster-mill concept based on a number of assumptions, an important one being the cast thickness.

7.2 Cast Thickness

To establish cast thickness requirements, it is essential to know the degree of reduction required to break down the columnar dendritic structure of the cast section and provide properties similar to conventionally-produced material. Recent literature suggests that the thickness must be reduced by somewhere between 2:1 and 5:1, the lesser reduction being applicable to the thinner cast sections of about 1 mm. In the following discussion, a 4:1 ratio is assumed, recognizing that if less reduction is ultimately established, then production costs will be less than developed in this study.

The majority of hot and cold-rolled sheet and strip is sold in the 0.7 to 3 mm thickness range. Because nearly half of the shipments are (hot-rolled) in the 2 to 3 mm range, then a cast thickness of 8 to 12 mm is a fundamental requirement to satisfy the current market for hot band.

Most of the other half of the shipments are (cold-rolled) in the 0.7 to 1.2 mm range, which would require a cast thickness range of 3 to 5 mm. However, most existing cold rolling facilities are sized for feeding material less than 3 mm thick. A change to feeding up to 5 mm thickness would require additional investment or cause a decrease in existing production capacity. For these reasons, it will be assumed that existing cold rolling facilities and operation remain unchanged, and would be fed 3 mm material, equivalent to conventional hot band.

In summary, it seems clear that if one cast thickness is adopted to satisfy the majority of gauges in the existing market for (hot and cold-rolled) sheet and strip, then 12 mm would be suitable. For the purpose of assessing costs in this study, a 12 mm thickness will be assumed, but is not intended as a recommendation.

8.0 CASTER-MILL CONCEPTS

Two tentative strip casting concepts have been assumed, one of large capacity applicable to integrated plants and one of small capacity applicable to minimills. Both are predicated on the production of "hot band equivalent", by continuously casting a 12 mm section that is hot direct-rolled to 3 mm thickness.

8.1 Large-Capacity Concept

To provide the necessary reduction, four hot-mill stands are assumed. On the premise that the cast strand is direct-rolled without additional heating, then the design speed of the caster should ideally be similar to conventional hot-mill speeds. In the finishing stands of a modern hot-mill, a 12 mm thick strand is processed at up to 4 m/s, which is beyond reach as a casting speed for this thickness. However, it is estimated that a 12 mm thick strand fed into a four-stand mill at 1 m/s would lose roughly the same temperature as a 25 mm bar fed to a conventional six-stand finishing mill. To achieve a final rolling temperature of 900°C, the cast strand would enter the first mill stand at about 1040°C.

Although a 12 mm thick strand has not been cast at 1 m/s, known solidification criteria suggest that it is theoretically feasible. With a vertical twin-belt or possibly a twin-roll caster concept, the strand would be fully solidified in a matter of seconds.

The vertical strand would be withdrawn though a 90° arc into a horizontal path. If the edges of the strand are significantly cooler than the centre, a temperature equalization section would be required before the strand enters the four-stand mill. A rotary shear would also be located between the caster and mill. At exit from the last mill stand, the top and bottom surfaces of the strand would be water-cooled to the required coiling temperature, before entering the coiler.

Fig. 16 illustrates the concept in diagrammatic form. The entire line may be about 200 m long, which is less than half the length of a conventional hot strip mill.

It is estimated that production capacity would be two to three million tonnes per year, depending on strip width and percent utilization. Yield is not easily determined, but it should be somewhat better than the yield of a conventional slab caster and hot-mill combination, which is about 90% from liquid steel to hot band.

Ideally, a complete new caster-mill facility of this type would be attached to an existing BOF steelmaking plant. The logistics of handling the steel ladle would be straightforward, being no different than supplying steel to a conventional slab caster. The mill stands and drives would be less costly than a conventional mill, as they would typically operate at a constant relatively slow speed, in synchronization with the caster. They would not have to be designed for zoom rolling as in modern conventional high-speed mills. As the process is essentially continuous, the weight of the coils produced (kg/mm width) would be virtually unlimited, whereas the coil size in a conventional operation is limited by the size of the cast slabs.

A less costly alternative would be the installation of a strip caster alone, directly onto the delay table of an existing hot strip mill. The delay table connects the roughing mill to the finishing mill, and is typically over 100 m long. This concept has a number of advantages and one major disadvantage, which is that large ladles of liquid steel would have to be conveyed from the BOF steelmaking plant to the hot-mill, which may produce routing difficulties at some plant sites. The advantages of this concept are in its flexibility. For example, it seems feasible to install the caster in a manner that would allow the hot-mill to operate in a conventional mode, processing slabs when the strip caster is not operating. It may also be feasible to install two strip casters in tandem on the delay table, thus providing increased production potential.

It is recognized that this high-capacity caster-mill concept is ambitious and may be difficult to achieve because of the high casting speed assumed. In which case, an alternative concept is to install two (or more) caster units to supply the mill unit. The cast strip would be maintained at high temperature by feeding it into a coil box which would be moved a short distance to the mill for hot rolling. This concept effectively decouples process units that have different production rates, while retaining most of the benefits of the strip casting process. However, its costs would be somewhat higher than the continuous direct-rolling process.

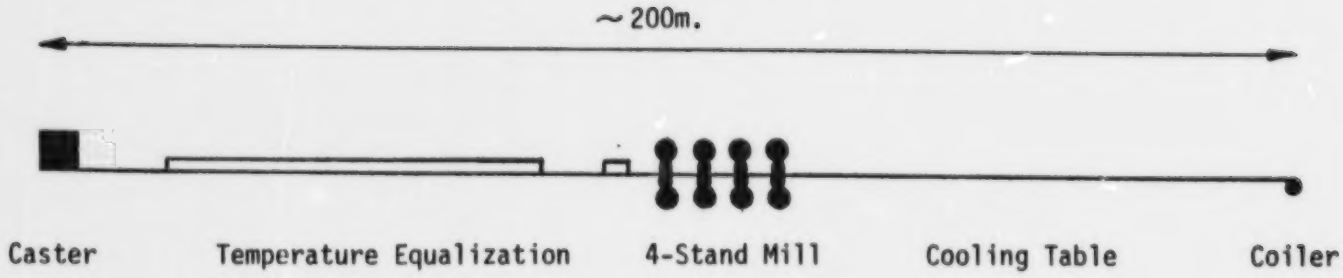
8.2 Small-Capacity Concept

To produce 500,000 tonnes/year of "hot band equivalent" from a 12 mm cast thickness would require an average cast speed of about 0.25 m/s. At this speed, additional reheat of the cast strand may be required before it enters the mill. The relatively low speed applied to a tandem mill would also necessitate reheating the strand between stands of the mill. To avoid additional reheating, a single-stand mill of planetary design is assumed. The 12 mm section would thus be directly hot-rolled to 3 mm thickness in one pass of the planetary mill. The strand emerging from the mill at about 1 m/s would be water-cooled before entering the coiler. It is worth noting that a single-stand planetary mill is capable of greater reduction than 75% and could therefore process a cast section significantly thicker than 12 mm.

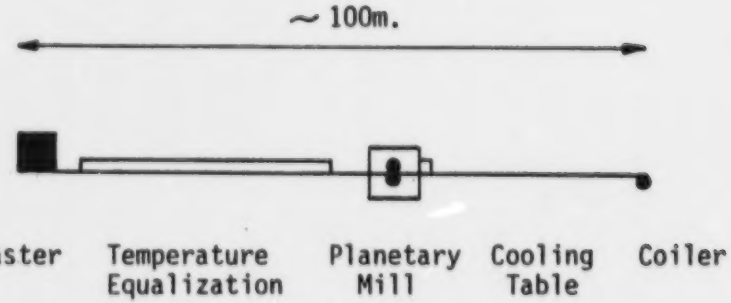
The small-capacity concept is thus similar to the large-capacity concept, but with only one mill stand and a relatively short strip cooling section. The entire facility would be significantly smaller, the equipment line being possibly 100 m long.

8.3 Commentary

It is probable that a longer development period would be required to approach the casting speed assumed for the large-capacity concept. Therefore, the small-capacity concept will likely achieve commercial operation before the large-capacity concept is fully developed.



LARGE-CAPACITY CONCEPT



SMALL-CAPACITY CONCEPT

FIGURE 16

9.0 COST ASSESSMENTS

It is recognized that the capital and operating cost assessment of a process that has yet to emerge beyond laboratory-scale development, is tenuous. A further consideration is whether the author is sympathetic or antagonistic to the outcome. It must, therefore, be noted that although the author's posture is sympathetic, a determined effort has been made to be entirely objective in assessing the costs.

9.1 Capital Costs

Large-Capacity Plant

For the large-capacity caster-mill concept, the capital cost assessment is essentially a judgement based on comparison with Dofasco's No. 2 Hot Strip mill. The major components of this facility include a two-high reversing roughing mill with edging, slab scarfer, delay table, rotary shear, five four-high finishing stands with a maximum finishing speed of 16 m/s, strip cooling table and one coiler. The total length of the mill equipment line excluding the soaking pits is about 400 m, and the published cost was $400 million.

In comparison, the major components of a strip caster-mill concept would include the caster unit, temperature equalization section, shear, four four-high finishing stands with an average finishing speed of 4 m/s, a relatively shorter strip cooling table and one coiler. On a comparative basis, it is believed that the total cost in current dollars may be in the $250 to $300 million range.

Small-Capacity Plant

For the small-capacity caster-mill concept, a factored estimate of the capital cost was developed from the following assumptions:

Caster unit purchase price	$12 million
Planetary mill purchase price	$22 million
Mill aisle area	3,000 m2

On this basis, the capital cost assessment is in the $100 to $125 million range.

Summary

To reconcile the costs for both sizes of plant, they are compared using the following empirical formula:

$$\frac{\text{Cost of Large Plant}}{\text{Cost of Small Plant}} = \left(\frac{\text{Capacity of Large Plant}}{\text{Capacity of Small Plant}}\right)^{0.7} = \left(\frac{2{,}000{,}000}{500{,}000}\right)^{0.7} = 2.64$$

This ratio narrows the cost ranges to:

$264 to $300 million for large-capacity plant. Use $290 million.

$100 to $114 million for small-capacity plant. Use $110 million.

Therefore the unit capital costs per tonne are:

Large-Capacity = $145 per annual tonne for 2 million tonnes

Small-Capacity = $220 per annual tonne for 500,000 tonnes

For the conventional integrated route, the following unit capital costs are based on available data for a large slab caster and hot strip mill:

Slab caster	=	$150 per annual tonne
Hot strip mill	=	$250 per annual tonne
Total		$400

These costs are diagrammatically shown in Fig. 18.

9.2 Capital Charges

The capital charge is the annual charge required to recover the capital and interest over a specific period, with equal annual payments. A 20% annual charge has been assumed.

	Unit Capital Cost ($/Annual tonne)	20% Capital Charge ($/tonne)
Conventional large slab caster	150	31 (Adjusted for yield)
Conventional large hot strip mill	250	50
Conventional Plant Total	400	81
Large-capacity strip caster-mill	145	29
Small-capacity strip caster-mill	220	44

9.3 Direct Operating Costs

Operating cost assessments for the conventional route have been built-up from available slab caster and hot mill data.

A similar built-up approach was used for the strip caster-mill concepts. In the case of the large-capacity plant, items such as labour, maintenance, refractories, power and other consumables were judged by comparison with available slab caster and hot mill data. However, for the small-capacity plant, the available operating data on planetary hot mills is limited and the costs are therefore less certain.

These assessments are summarized as follows and are diagrammatically illustrated in Fig. 17. They are strictly the costs for conversion of liquid steel to hot band, excluding the metal costs and overheads. The slab caster figure is based on a conversion cost of $25 per tonne slab, adjusted for hot mill yield.

Conventional large slab caster	$26 per tonne hot band
Conventional large hot mill	$50 per tonne hot band
Conventional Plant Total	$76 per tonne hot band
Large-capacity strip caster-mill	$30-$35 per tonne hot band
Small-capacity strip caster-mill	$50-$70 per tonne hot band

Thus, a large-capacity strip caster-mill could show direct operating savings of about $40 to $45 per tonne. A small-capacity unit could show savings in the range of $5 to $25 per tonne.

9.4 Production Cost Summary

The following costs are $ per tonne hot band.

	Conventional Integrated Plant	Strip Caster-Mill Large	Strip Caster-Mill Small
Direct Operating Cost	76	30-35	50-70
Capital Charge	81	29	44
Total Production Cost	157	59-64	94-114
Saving over conventional route		93-98	43-63
		Say 95	Say 55

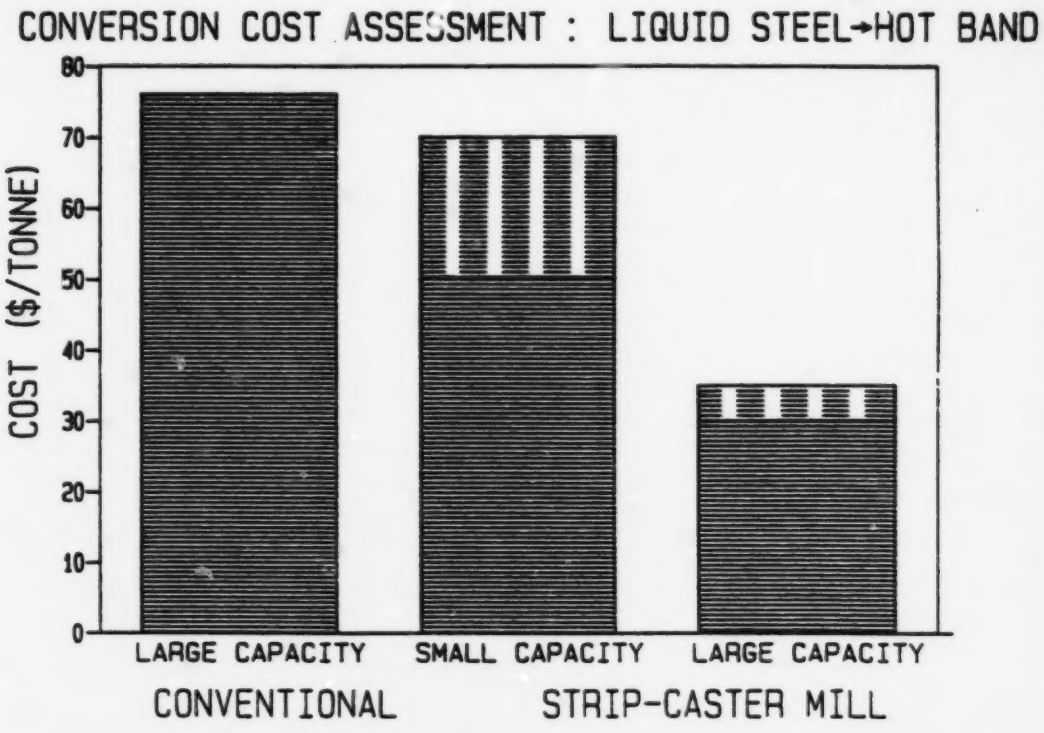


FIGURE 17

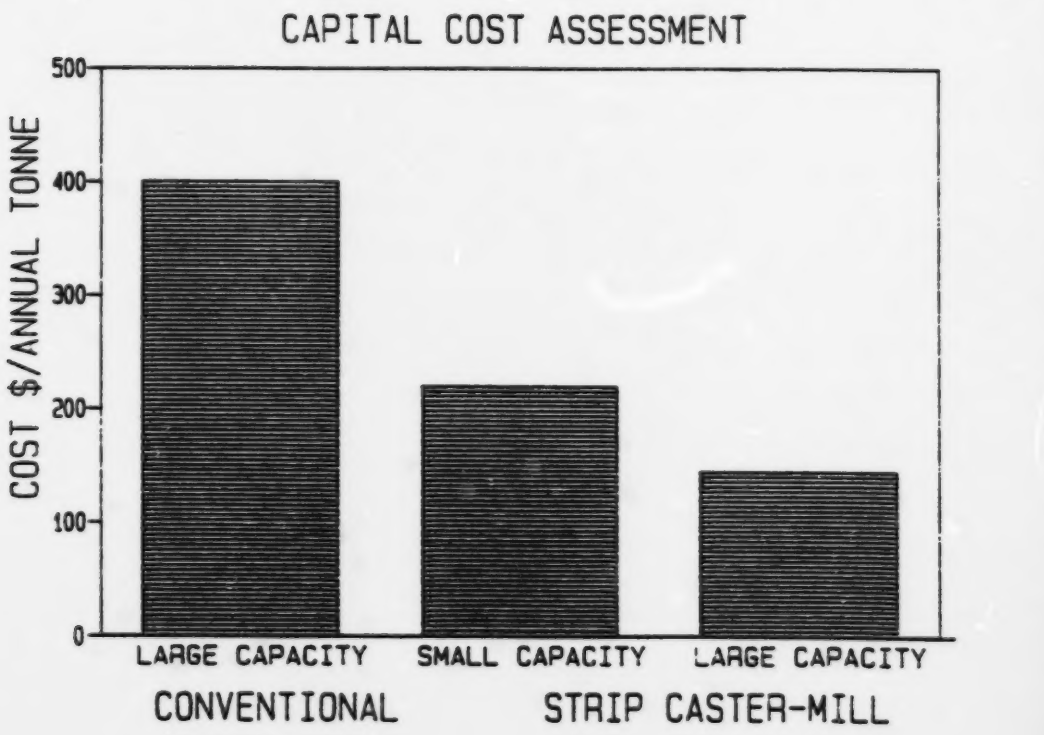


FIGURE 18

10.0 MINIMILLS

The growth of minimills in the last 25 years is attributed to their adoption of advanced technology, such as electric furnaces and continuous billet casters, and an adequate supply of relatively inexpensive raw material in the form of steel scrap. The relatively low capital cost of electric furnaces facilitated the construction of steelmaking facilities at a fraction of the unit cost of integrated plants. Their cost structure has allowed them to compete successfully with integrated plants for products such as rod, bar and smaller structural sections. There are fifteen minimill meltshops in Canada with a total steelmaking capacity of about 5 million tonnes per year, which is roughly 30% of the national capacity.

With the exceptions of Sidbec in Quebec and Hylsa in Mexico, both of which are relatively large and integrated to be labelled minimills, no minimill in North America produces rolled sheet and strip. The advent of a viable thin strip casting process would provide the scrap-based minimills with an opportunity to enter this market.

The production cost of liquid steel in the electric furnace is sensitive to the price of purchased scrap and electricity. The price of electric power depends on plant location, whereas scrap is a commodity subject to significant price swings related to the business cycle. The long-term trend adjusted for inflation suggests that the price of scrap has been declining at about 1% per year.

If sheet and strip for deep-drawing applications is produced by a minimill, it would face a change in steelmaking practices to satisfy the more-demanding metallurgical requirements. The drawability of sheet is inhibited by the presence of residual elements, such as copper, tin, chrome, nickel and molybdenum. For the various drawing qualities, the sum of these residuals must be 0.16% and less. The implication is that the minimill would have to purchase good scrap containing minimal residuals (#1 Bundles, Clips, Bushellings), or use a percentage of direct-reduced iron (DRI) in the

furnace charge, to dilute the residuals. In either case, steelmaking costs will increase. If merchant DRI costs roughly the same as blast furnace hot metal, the liquid steel costs could exceed the comparable costs in an integrated plant.

For these reasons, the scrap-based minimills may avoid the "drawing quality" grades and concentrate on "commercial quality" products that have less-demanding metallurgical requirements.

A U.S. minimill (Nucor) has estimated that for drum stock, decking and siding and other such products not requiring deep drawing or forming, the U.S. market exceeds 10 million tons per year. This figure represents about 25% of all U.S. sheet and strip production. Assuming the same percentage, the Canadian market for similar products would be 1.4 million tonnes. It is believed that the market for all "commercial quality" sheet and strip is substantially larger. These data suggest that Canadian markets could support three minimills of about 500,000 tonnes/year capacity each.

If a minimill planned to market only the thicker (hot-rolled) gauges, then it may seek the process concept previously described. This approach would not preclude subsequent addition of cold rolling facilities to expand the product line.

If the minimill were to consider only the thinner gauges, then casting 6 mm thick material followed by reduction of 4:1 or more, would provide the majority of the (cold-rolled) gauges.

11.0 JUSTIFICATION FOR A CANADIAN PROGRAMME

The body of this report has developed a scenario which is summarized by the following key points:

11.1 Status of Strip Casting

- Alternative processes are under active development in Japan, Europe and the U.S.A.
- Most of the development work appears to be in Japan, principally in the laboratories of the largest steel producers.
- Some programmes have been in place for three or four years.
- No process has reached "tonnage" production, but one or two may be close to commercial adoption.
- A major Japanese steel company has stated that it will likely adopt one of the new casting processes in the next decade.
- It has been demonstrated that (stainless steel) strip can be produced with properties equivalent to conventionally-produced material.

11.2 Justification for Strip Casting

- A strip caster will be less expensive than a conventional slab caster of equal capacity, because of the nature of the solidification process.
- As the number of passes required to roll a thin section to finished thickness is less than for a conventional slab, the rolling costs will be lower.

- As thin strip would be cast at relatively high speed, it is more suitable for direct rolling with little or no reheating, once again saving costs.

- A tentative assessment of potential benefits indicates direct operating cost savings of up to $45 per tonne compared with the conventional slab caster and hot mill process.

- Total savings will ultimately depend on cast thickness and speed, as well as on economies of scale and treatment of capital.

11.3 Conclusion

It is obvious that if a viable strip-casting process is commercially accepted, then it will immediately present a threat to other sheet and strip producers because its costs are lower than competing processes. Thus, companies adopting the process will have the opportunity to increase their share of the steel market and increase their profitability. With a domestic steel market that is in a levelling trend and may subsequently decline, a low-cost process could well be a key to the survival of Canada's sheet and strip industry.

The first tangible evidence of commercial acceptance occurred in December 1986 when Nucor, an innovative and successful U.S. low-cost minimill operator, placed an order with SMS-Concast for a thin-slab caster and a four-stand hot mill. The plant will start operation in 1989.

Also in 1986, Kawasaki Steel indicated that some of its facilities scheduled for revamp in the nineteen-nineties will incorporate thin slab casting.

It is now clear that the commercialization of thin slab casting is imminent and will be an intermediate step towards the subsequent adoption of strip casting.

The window of opportunity for Canada to initiate the development of strip casting, seems to be closing rapidly. If the opportunity is lost, the only remaining course will be to purchase the process. In the current business environment, it is questionable whether a steel company that has developed the process for its own advantage will sell it to a potential competitor in good time and under acceptable terms and conditions. Which leaves the remaining alternative of purchasing the process from an equipment supplier and accepting the risk that the equipment has not been fully developed and may require considerable time and expense to become a viable production process.

- A Canadian steel strip-casting development programme will minimize these potential problems.

- It will marshal the world-class research talent that exists in Canadian Universities and provide a focus for Government and Industry laboratories.

- It would automatically build a nucleus of skilled personnel with acquired strip-casting knowledge and experience.

- It is also likely that the development work will contribute to other processes and technologies.

There is no doubt that the research talent in Canada is second to none in fields such as steelmaking, fluid flow, electromagnetics, ceramics, heat transfer, solidification, solid processing and sensors, all of which are fundamental to strip-casting. As it is evident that strip-casting must be adopted by the steel-industry to remain competitive, an R&D programme would clearly be of mutual benefit to industry and research. Furthermore, the importance of effectively bridging the gap between basic research and applied development, has been repeatedly demonstrated in the adoption of new commercial processes in the past.